SOLAR CORONAL MODELING FOR CCMC APPLICATIONS

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SCIENCE APPLICATIONS INTL. CORP.
SAN DIEGO

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OUTLINE

- Highlights of the coronal MHD model MAS
  - Polytropic MHD model
  - MHD model with an improved energy equation
- Present capabilities of MAS at CCMC
- Planned improvements

MAS Model Highlights

- MAS has been around for ~ 15 years
- It is built on a rich base of experience in computational physics and the modeling of solar coronal and fusion plasmas
- Features:
  - Time-dependent resistive MHD
  - Incorporation of observed photospheric magnetic field data
  - Evolution of boundary data
  - Coronal and heliospheric components
  - Non-uniform meshes (structured)
  - 3D finite differences in spherical (r,θ,ϕ) coordinates
  - Implicit and semi-implicit time differencing
  - Comprehensive physics model including the solar wind and energy transport (radiation, parallel thermal conduction, heating, and Alfvén waves)
  - Has been used to model CMEs

MAS MODEL HIGHLIGHTS (CONT.)

- Written in FORTRAN 90
- Designed to run on massively parallel computers using MPI
  - IBM/SP3 + SP4 (xlf)
  - Linux & Beowulf (lf95, pgf90, Intel Fortran)
  - Mac (Absoft and xlf)
  - SGI/Altix (ifort)
- Mesh decomposition among processors in 3D
- Dynamic allocation allows mesh size and number of processors to be selected at run time
- Restart capability using HDF files (for long runs)
- Many applications and comparisons with observational data (eclipses, IPS, *in situ* solar wind measurements, coronal holes, pB images, current sheet topology and spacecraft crossings, CMEs)
- A rich set of post-processing tools has been developed

MHD Equations
(Polytropic Model)

$$\nabla \times \mathbf{B} = \frac{4\pi}{c}\mathbf{J}$$

$$\nabla \times \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}$$

$$\mathbf{E} + \frac{1}{c}\mathbf{v} \times \mathbf{B} = \eta \mathbf{J}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}\right) = \frac{1}{c}\mathbf{J} \times \mathbf{B} - \nabla p + \rho \mathbf{g} + \nabla \cdot (\nu \rho \nabla \mathbf{v})$$

$$\frac{\partial p}{\partial t} + \nabla \cdot (p \mathbf{v}) = -(\gamma - 1) p \nabla \cdot \mathbf{v}$$

$\gamma = 1.05$ in the corona
$\gamma = 1.5$ in the heliosphere

MHD Equations
(Improved Energy Equation Model)

$$\nabla \times \mathbf{B} = \frac{4\pi}{c}\mathbf{J}$$

$$\nabla \times \mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t}$$

$$\mathbf{E} + \frac{1}{c}\mathbf{v} \times \mathbf{B} = \eta \mathbf{J}$$

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho \mathbf{v}) = 0$$

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\ \mathbf{v}\right) = \frac{1}{c}\mathbf{J} \times \mathbf{B} - \nabla p - \nabla p_w + \rho \mathbf{g} + \nabla\cdot(\nu\rho\nabla\mathbf{v})$$

$$\frac{\partial p}{\partial t} + \nabla\cdot(p\mathbf{v}) = (\gamma - 1)\left(-p\nabla\cdot\mathbf{v} - \nabla\cdot\mathbf{q} - n_e n_p Q(T) + H\right)$$

$$\gamma = 5/3$$

$$\mathbf{q} = -\kappa_{\parallel}\hat{\mathbf{b}}\hat{\mathbf{b}}\cdot\nabla T \qquad \text{(Close to the Sun, } r \lesssim 10R_S\text{)}$$

$$\mathbf{q} = 2\alpha n_e T\hat{\mathbf{b}}\hat{\mathbf{b}}\cdot\mathbf{v}/(\gamma - 1) \qquad \text{(Far from the Sun, } r \gtrsim 10R_S\text{)}$$

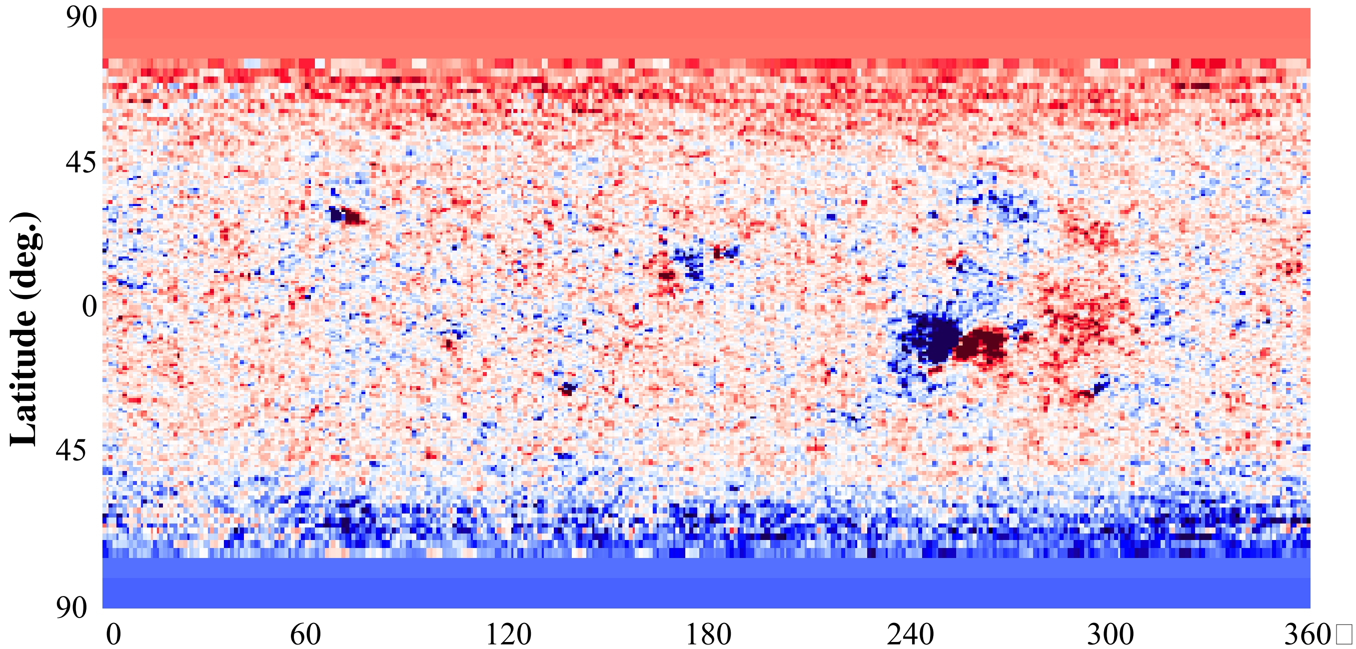
+ WKB equations for Alfvén wave pressure p_w evolution

PRESENT CAPABILITIES OF MAS AT CCMC

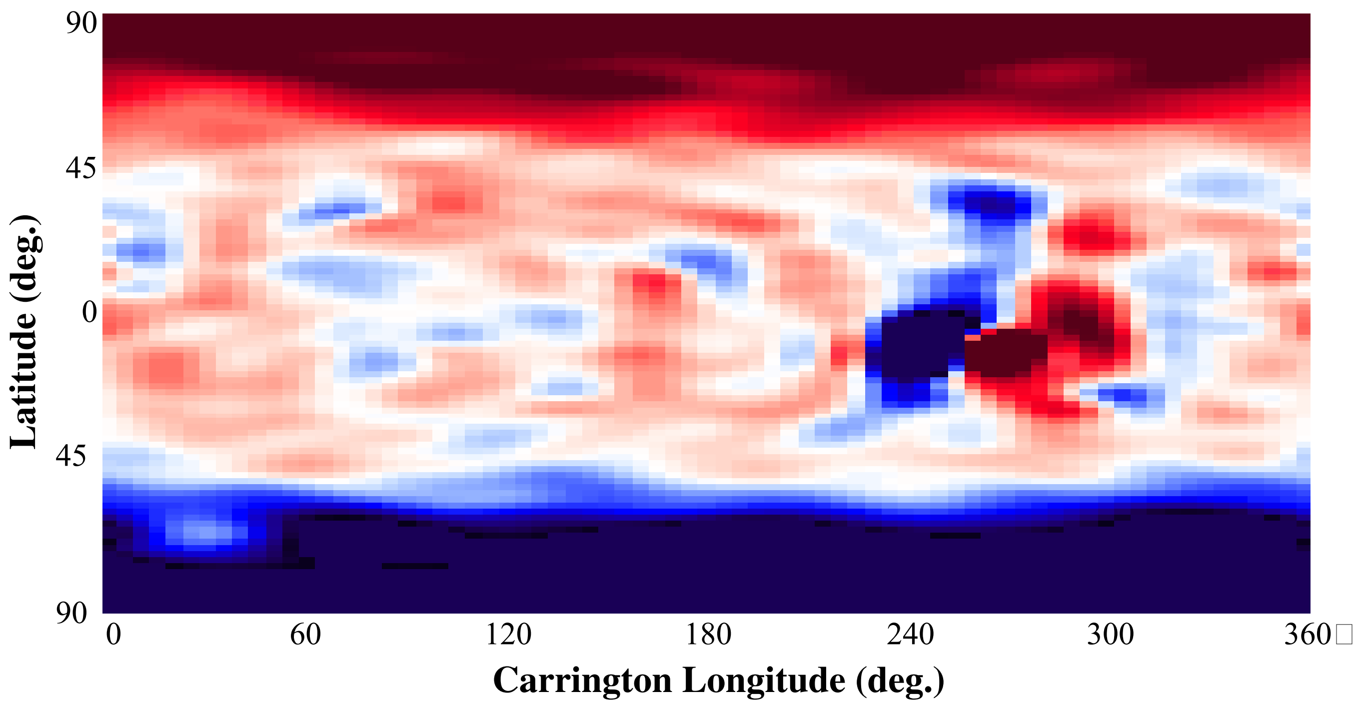
- The capabilities of the MAS model at CCMC have been deliberately curtailed
- A conservative approach has been used to minimize the chance of code failure
- Intrinsically, this is a research code that is being made available to users in the belief that this may prove to be a useful exercise
- Capabilities of MAS at CCMC:
  - Polytropic MHD model
  - Driven by (filtered) Kitt Peak/SOLIS magnetic field maps
  - Choice of low ($61 \times 51 \times 32$) and medium ($85 \times 81 \times 64$) resolution meshes
  - Choice of base density and temperature in the corona
  - Relaxation to steady state
  - Increased viscosity and resistivity
  - Runs on a single CPU

Whole Sun Month
Aug. 10 – Sep. 8, 1996

Kitt Peak Synoptic Chart, B_r



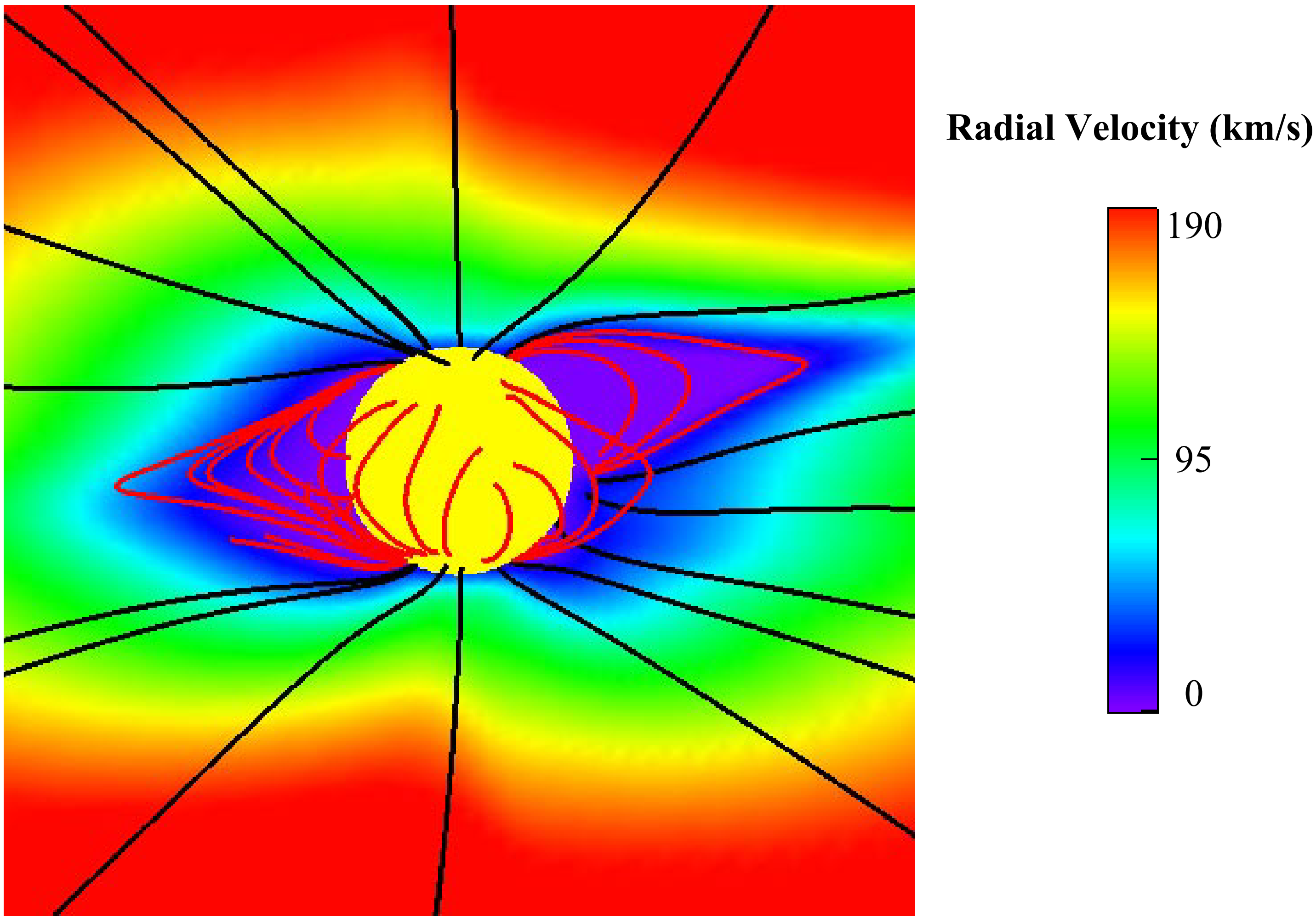
Smoothed Magnetic Field (used in MHD model)



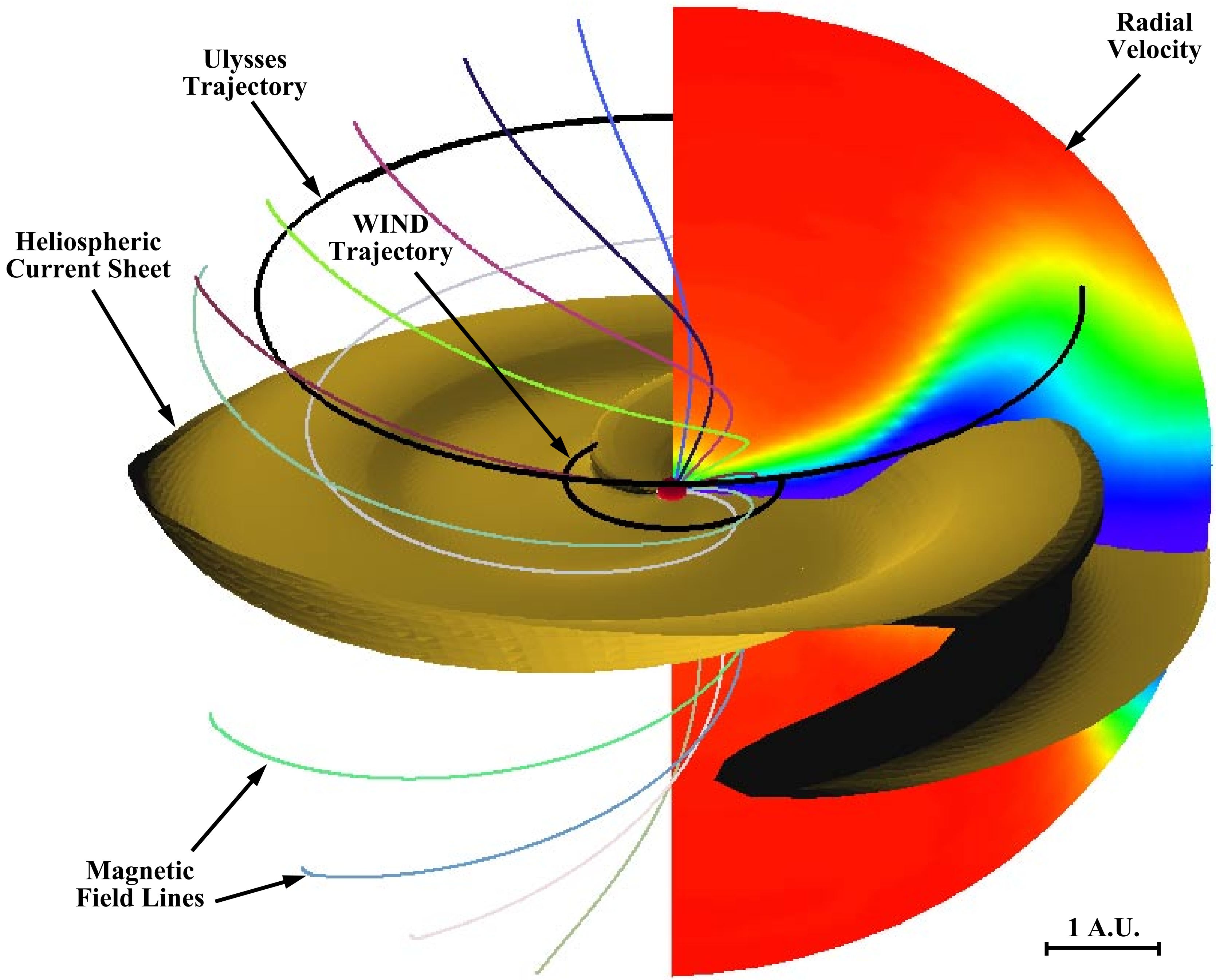
Whole Sun Month

Aug. 10 – Sep. 8, 1996

Radial Velocity
Open and Closed Field Lines

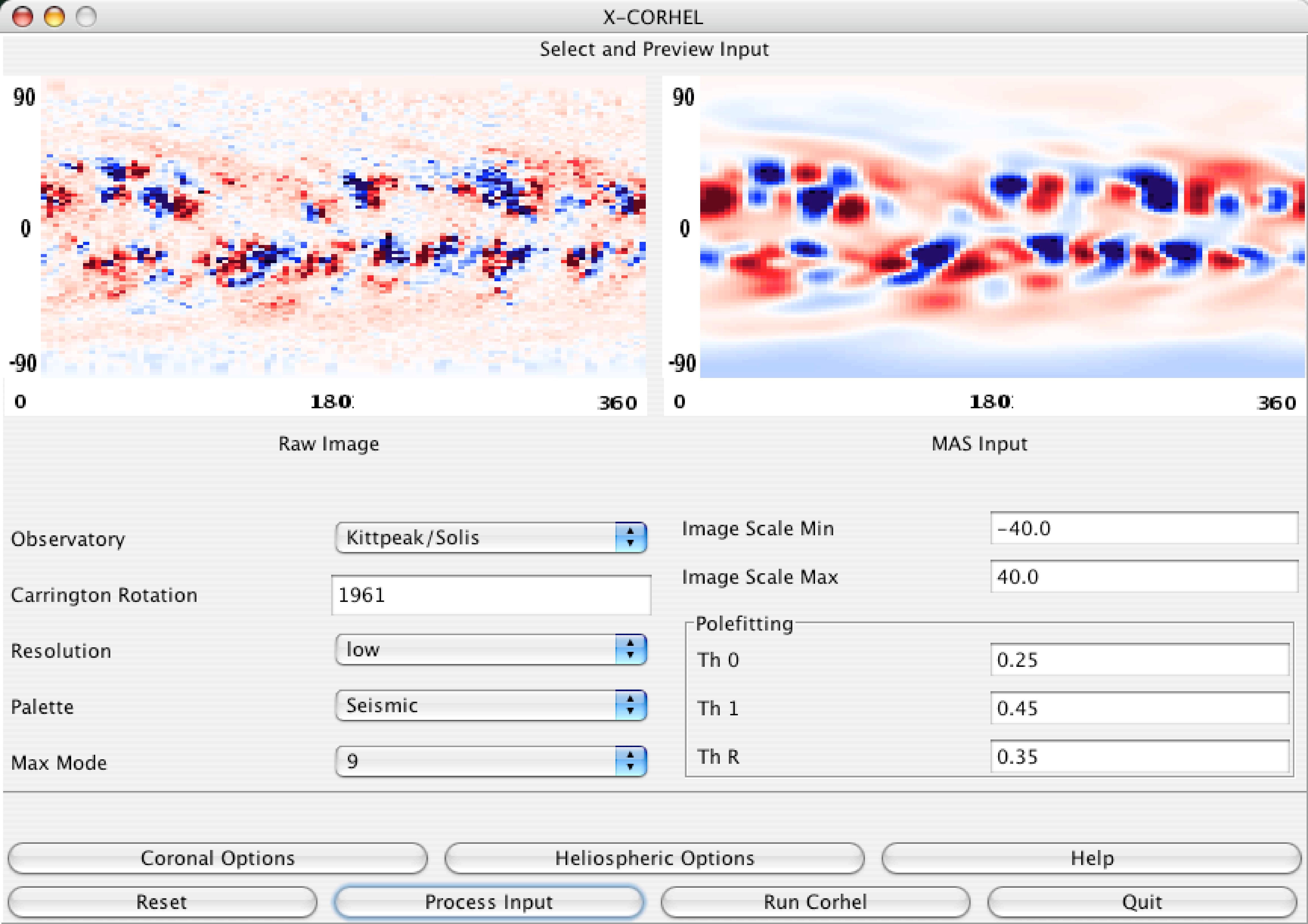


The Heliosphere During Whole Sun Month
August September 1996



PLANNED IMPROVEMENTS

- Add more flexibility to MAS at CCMC:
  - Magnetic field from other observatories
    (Mt. Wilson, WSO, MDI)
  - "Fractional" Carrington rotations
  - Improved visualization and post-processing (interactive field lines, flying spacecraft trajectories through the model results)
  - Runs with evolution of boundary data
  - User-supplied magnetic field boundary data
  - Generation of higher-level data products
  - Implementation of the model with an improved energy equation $\Rightarrow$ better solar wind model
- Implementation of the (new) MPI version of MAS
- Coupling to a heliospheric model (ENLIL): in progress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Raw Image
MAS Input
Observatory
Kittpeak/Solis
Carrington Rotation
1961
Resolution
low
Palette
Seismic
Max Mode
9
Image Scale Min
-40.0
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Coronal Options
Heliospheric Options
Help
Reset
Process Input
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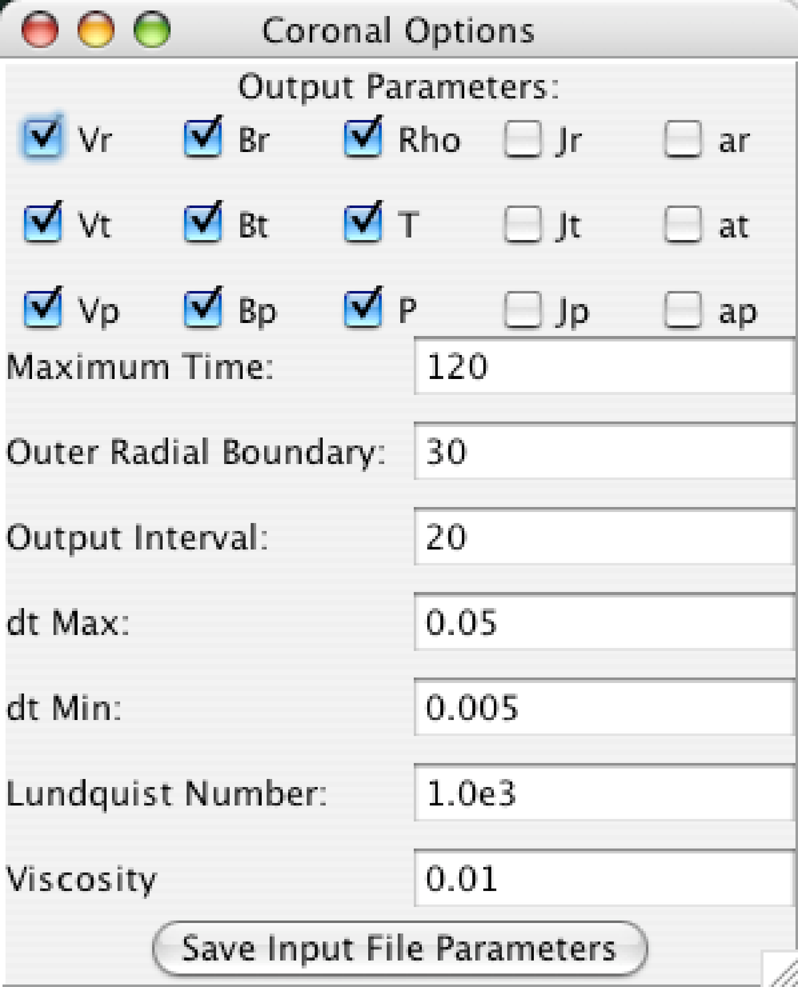
Coronal Options
Output Parameters:
Vr
Br
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Maximum Time:
120
Outer Radial Boundary:
30
Output Interval:
20
dt Max:
0.05
dt Min:
0.005
Lundquist Number:
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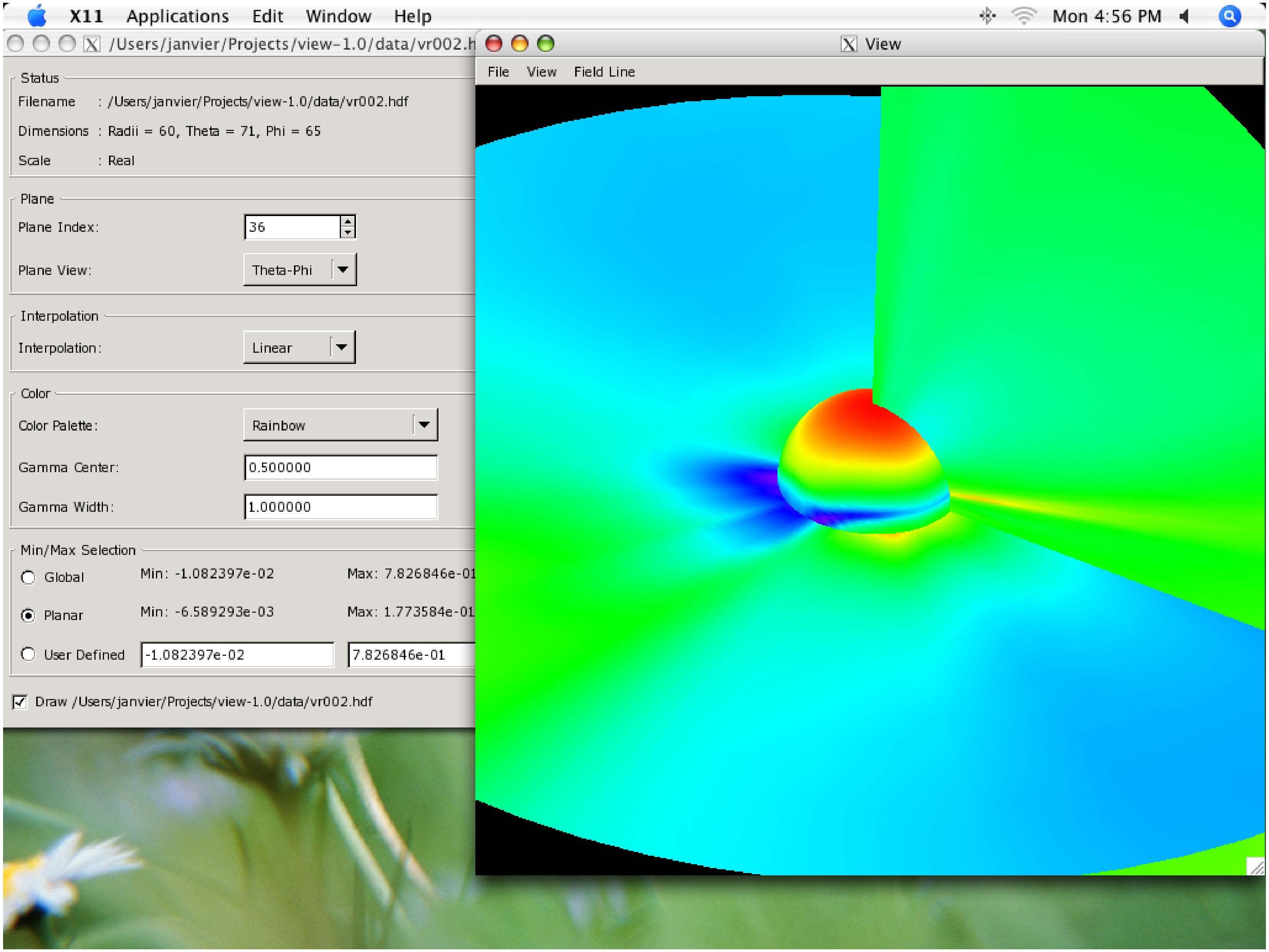
Viscosity
0.01
Save Input File Parameters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Dimensions : Radii = 60, Theta = 71, Phi = 65
Scale : Real
Plane
Plane Index: 36
Plane View: Theta-Phi
Interpolation
Interpolation: Linear
Color
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Gamma Center: 0.500000
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Global Min: -1.082397e-02 Max: 7.826846e-01
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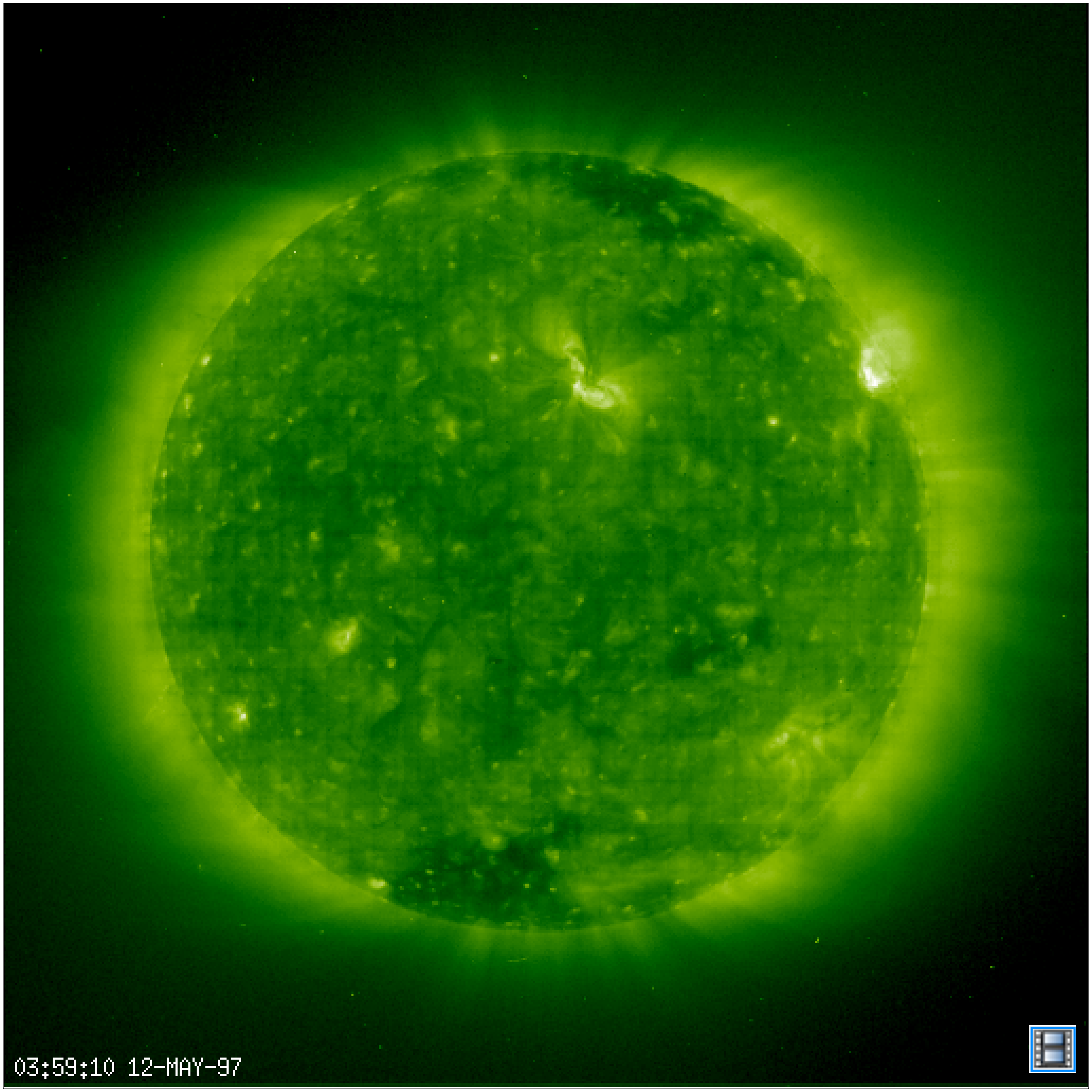
Draw /Users/janvier/Projects/view-1.0/data/vr002.hdf

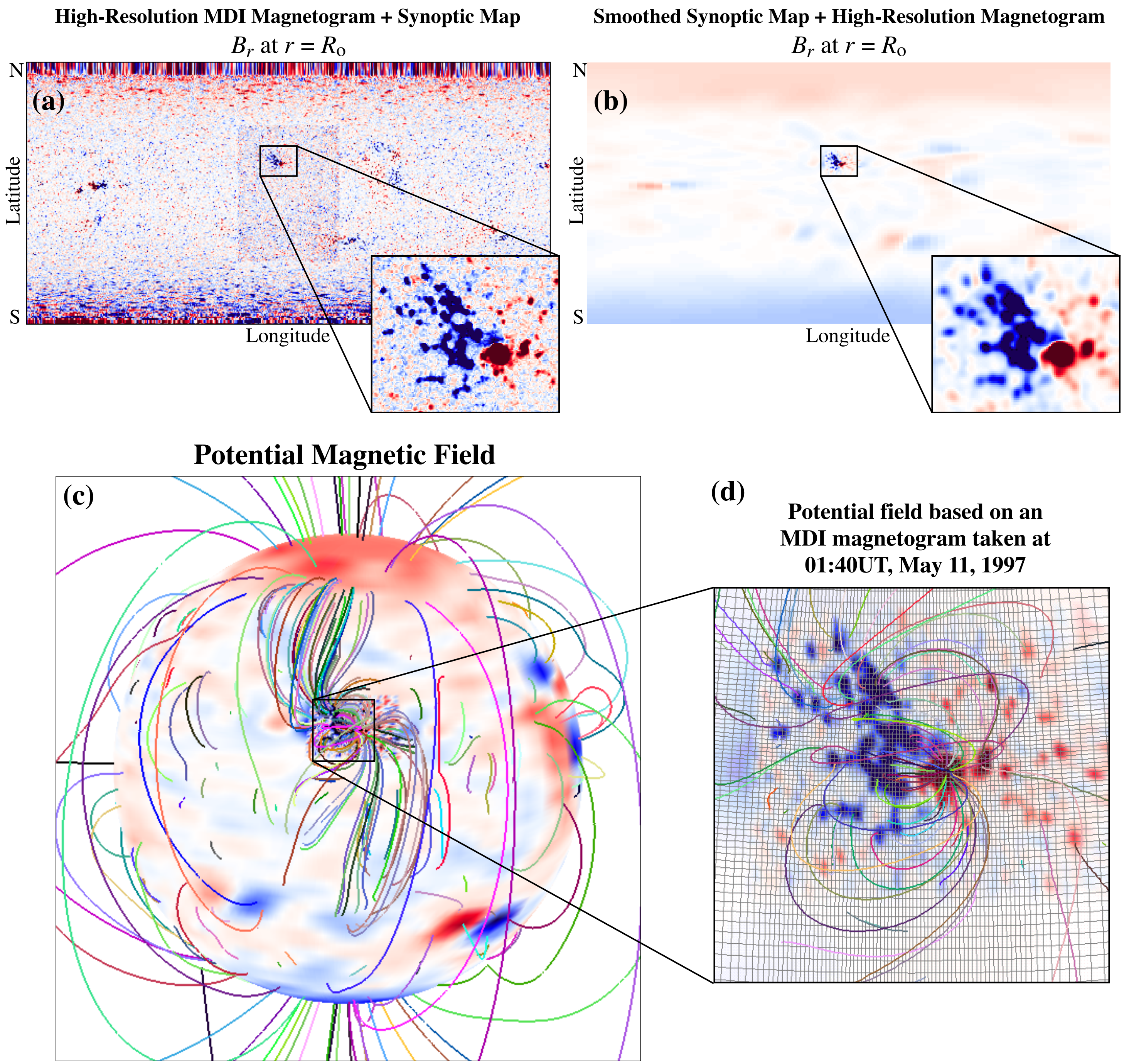
PHYSICS ADVANCES ON THE HORIZON

- Desire to model fast CMEs ($\gtrsim 1{,}000\,$km/s)
- Requires stronger (active region) magnetic fields ~ 2 kG
- Requires smaller (active region) length scales ~ 100,000 km
- Desire to study CME events (e.g., May 12, 1997)
- Elements of CME initiation:
  - Initial equilibrium specification (p, ρ, $\mathbf{B}$, solar wind)
  - Energization [e.g., shear flow profile $\mathbf{v}_t(\mathbf{x},t)$, twist profile $\alpha(\mathbf{x},t)$, eventually vector magnetograms]
  - Trigger mechanism [e.g., flux cancellation $B_r(\mathbf{x},t)$, or continued shear flows]

May 12, 1997 CME: EIT 195Å

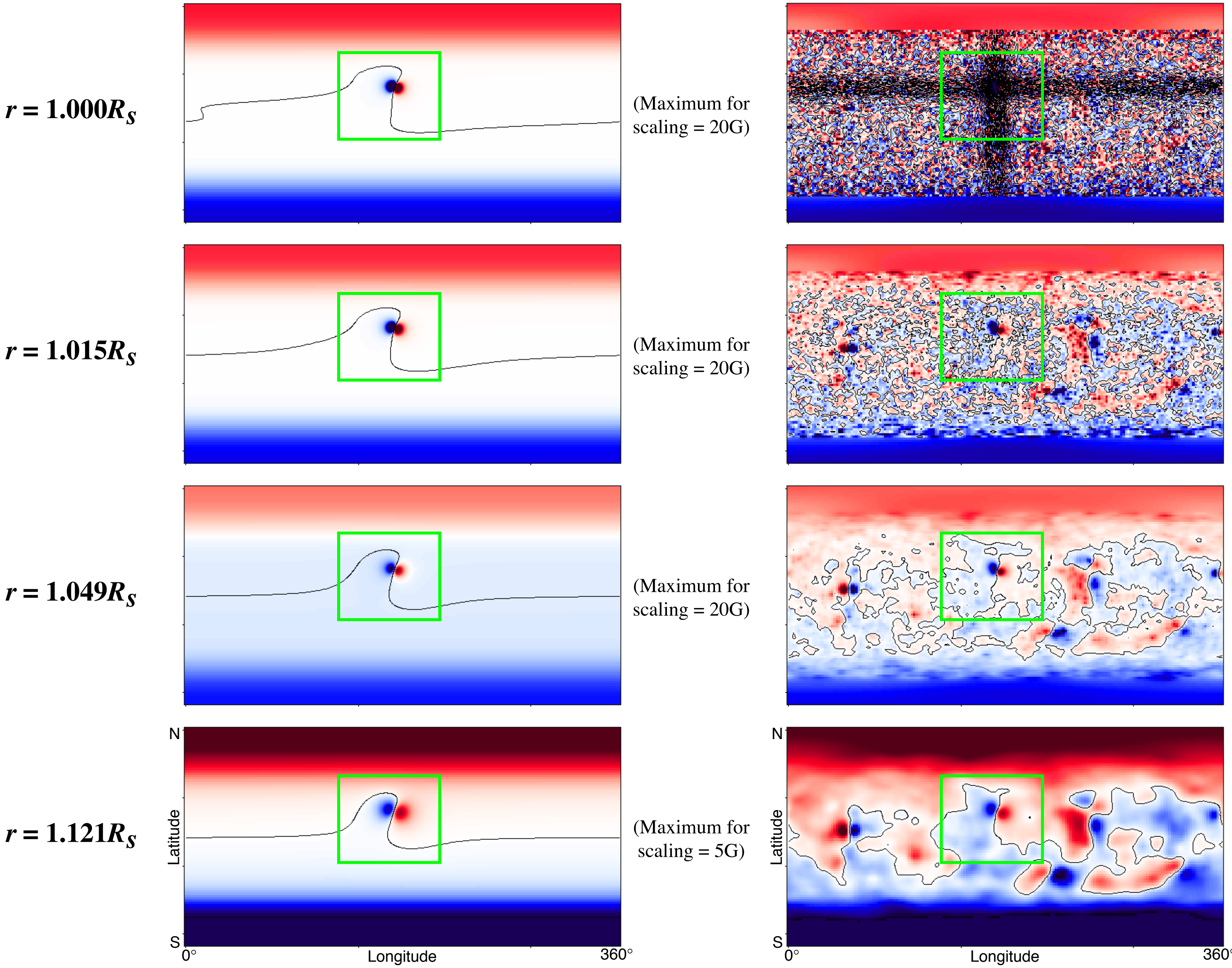


May 11, 1997 Magnetic Field

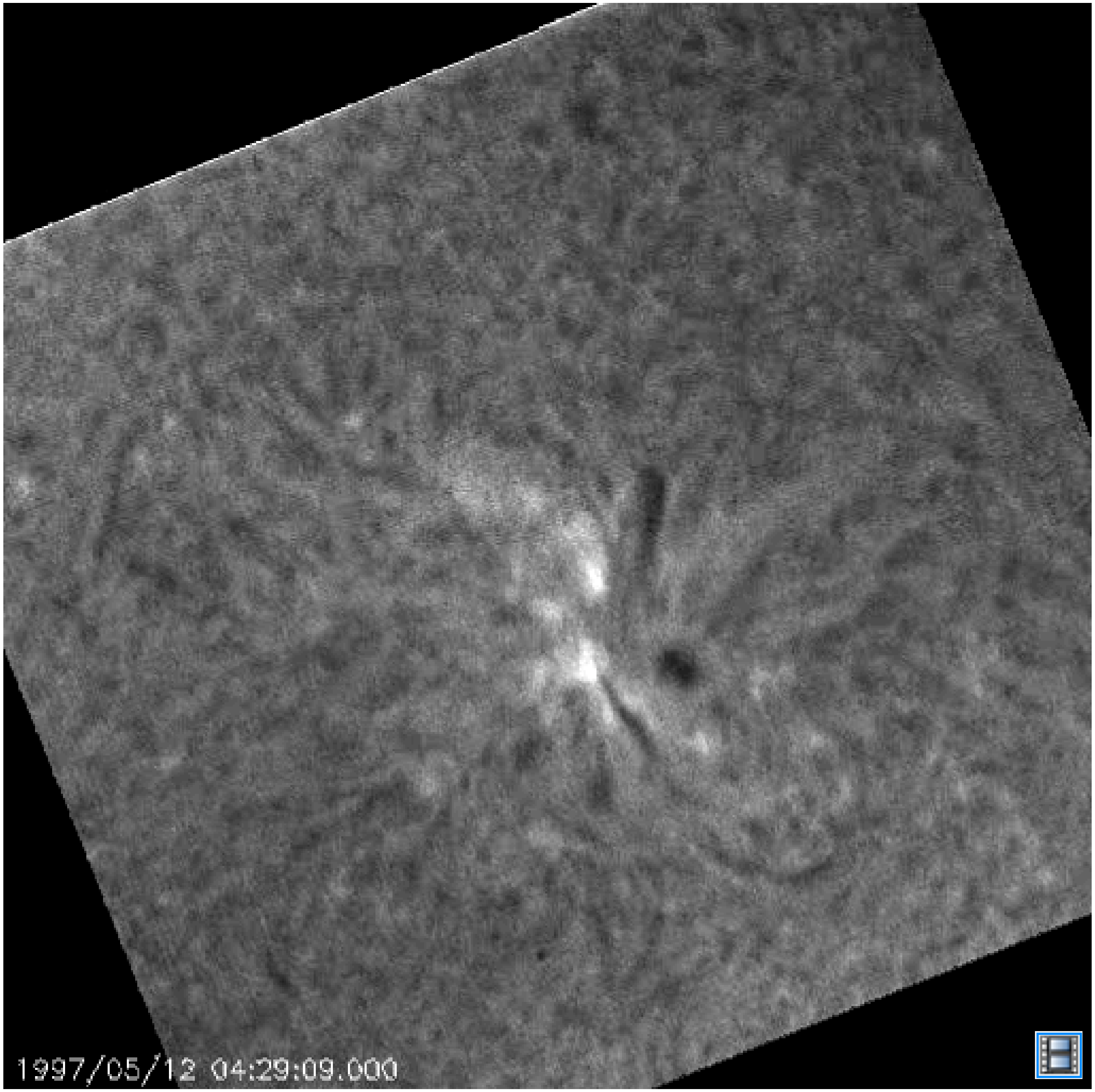


Comparing MDI Data with a Simple Model of the Magnetic Field on May 11, 1997

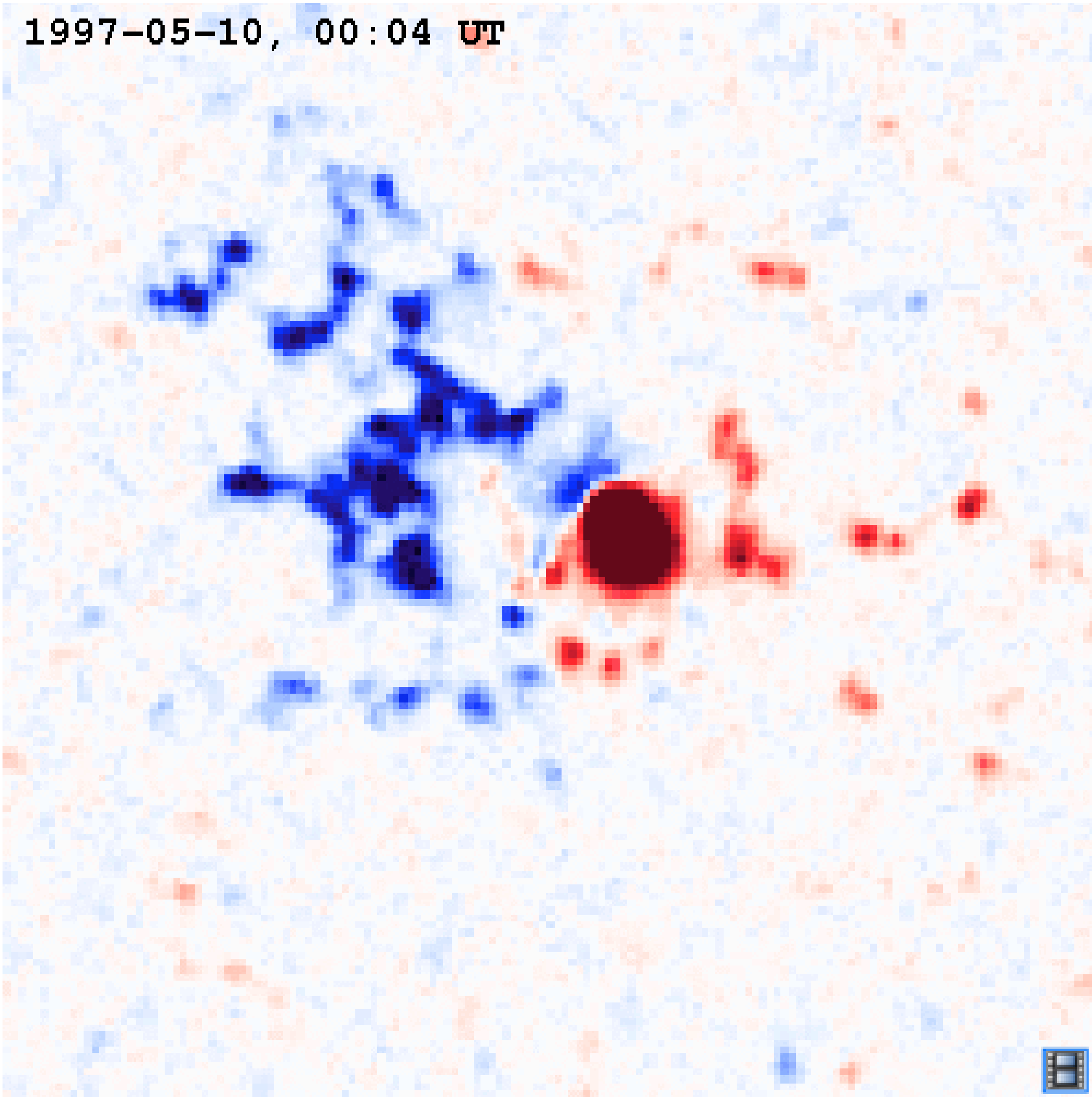
(Model: Large Scale Axisymmetric Field + Bipole)



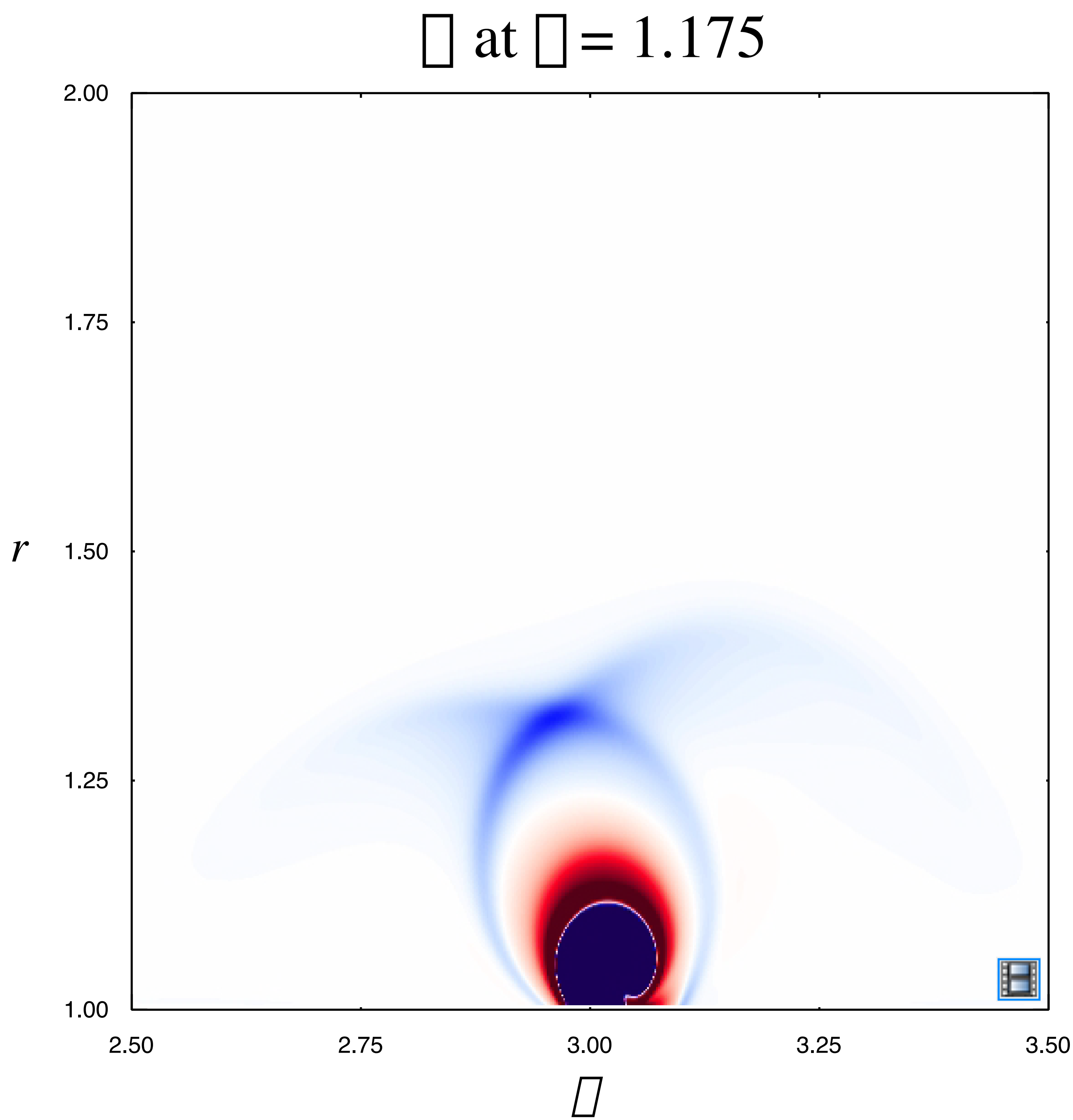
May 12, 1997 CME: H-α□



Flux Cancellation Preceded the Event



C1.3 Flare Occurred in AR8038 on May 12, 1997 at 04:42UT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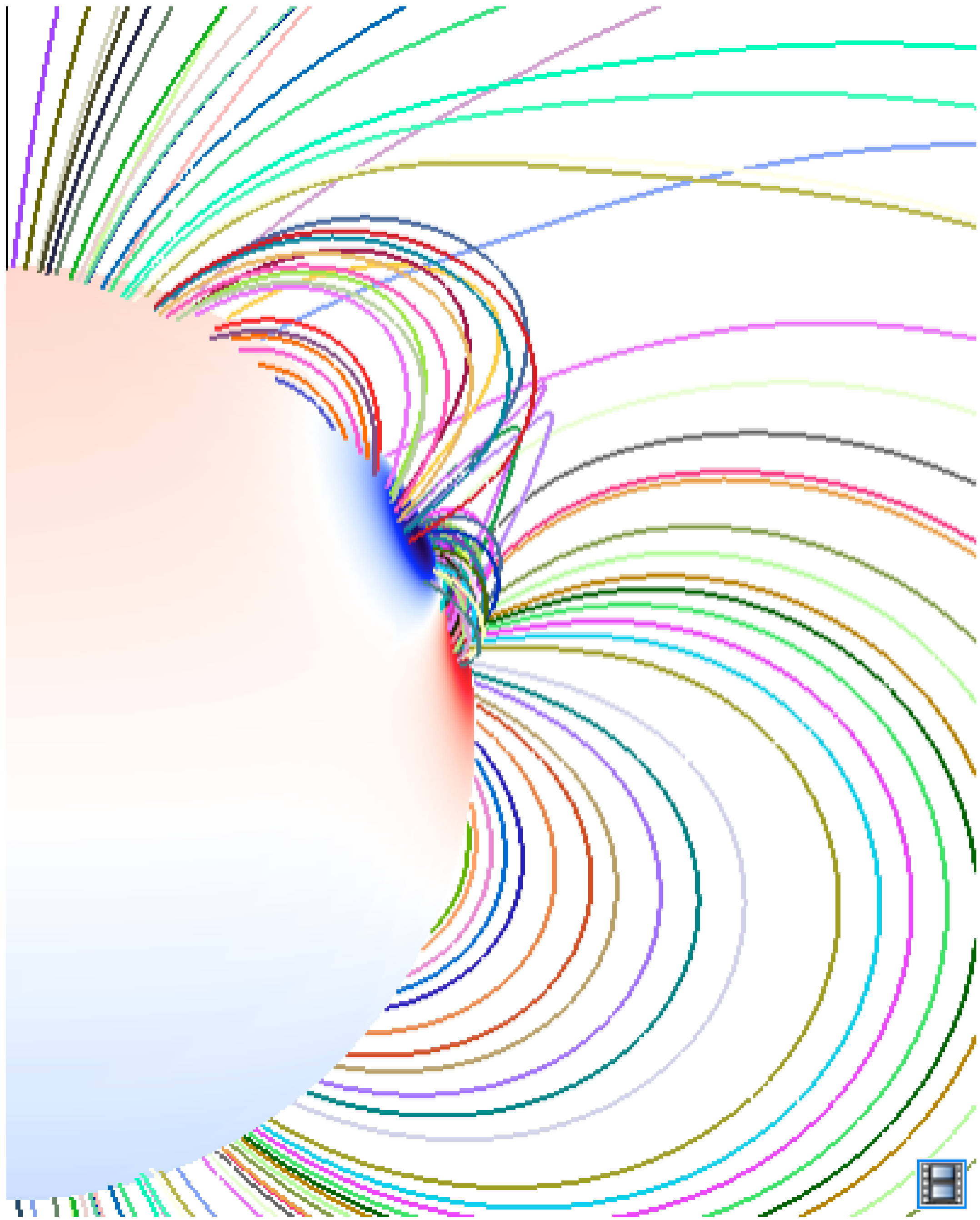
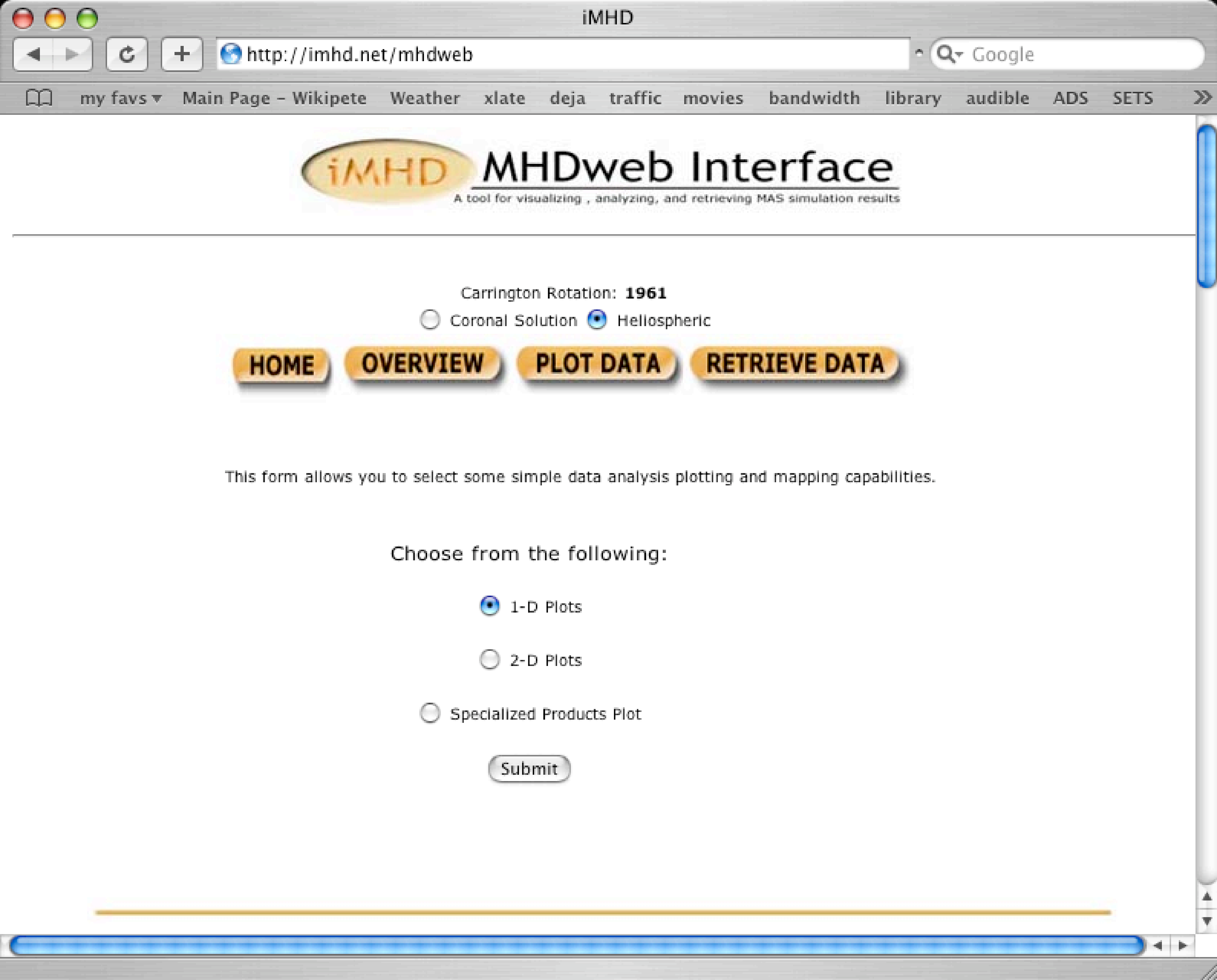


AR65A+B

DATABASE OF MHD RUNS

- We have a database of ~ 29 years of 3D MHD runs (~ 383 Carrington rotations): `http://iMHD.net/mhdweb`
- Coronal simulations (up to 30 R_S)
- Heliospheric simulations (up to 1 AU)
- Using the polytropic model
- Summary plots: HCS, coronal hole maps, standard slices, time histories
- Interactive plots: 1D, 2D slices, pB
- Ability to retrieve the model output fields (HDF files)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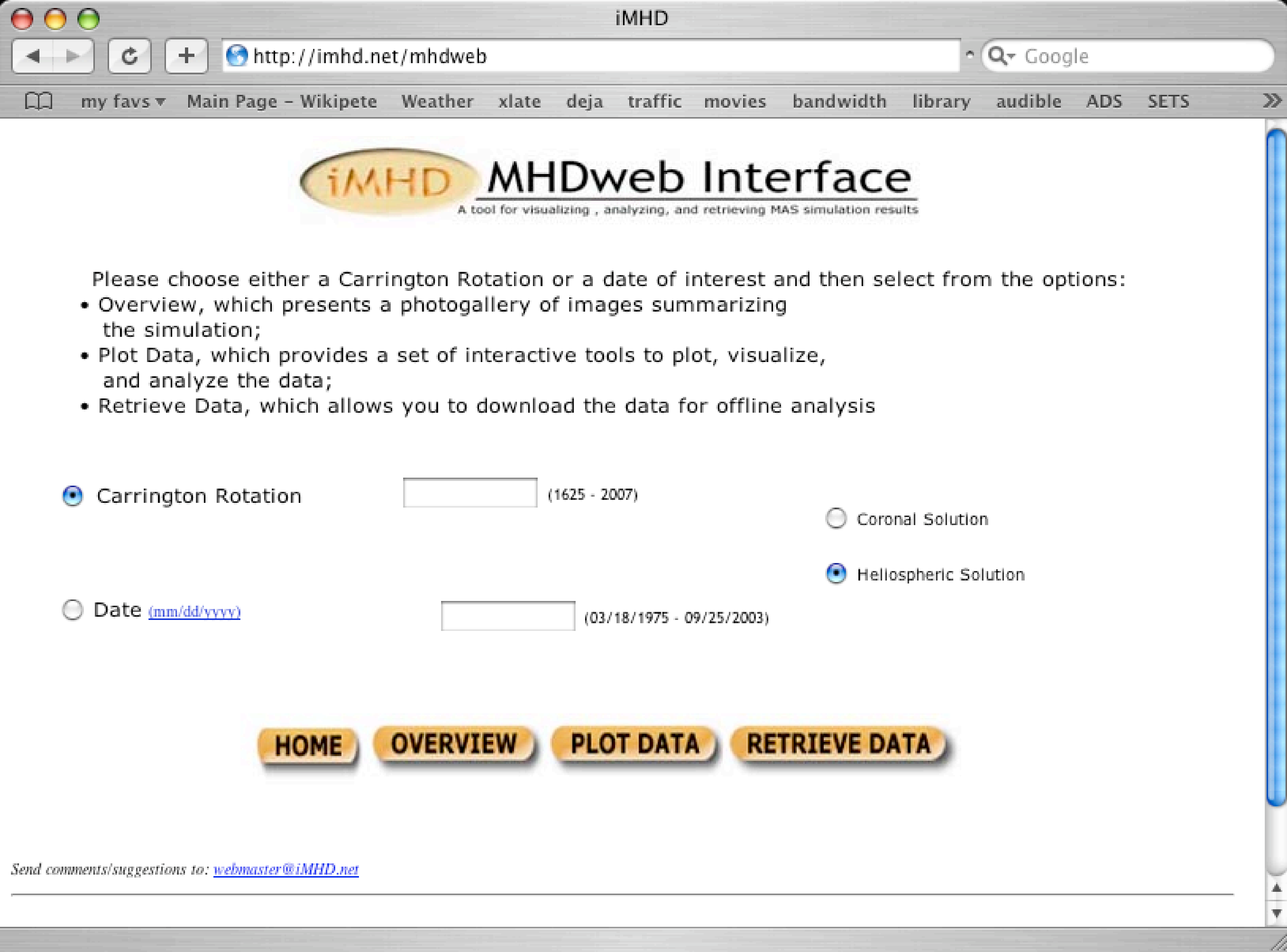
iMHD
MHDweb Interface
A tool for visualizing , analyzing, and retrieving MAS simulation results
Carrington Rotation: 1961
Coronal Solution
Heliospheric
HOME
OVERVIEW
PLOT DATA
RETRIEVE DATA
This form allows you to select some simple data analysis plotting and mapping capabilities.
Choose from the following:
1-D Plots
2-D Plots
Specialized Products Plot
Submit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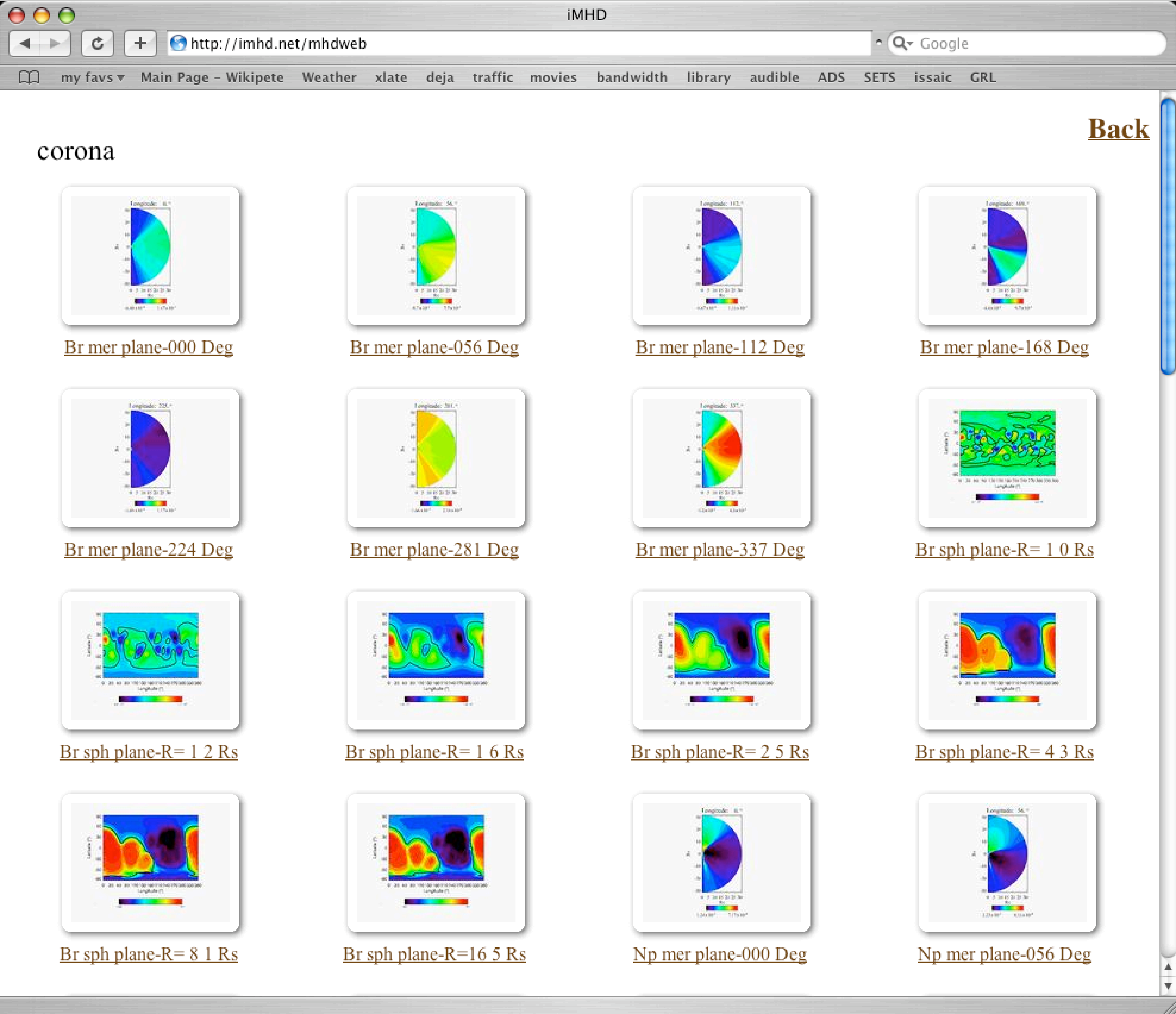
SETS
iMHD
MHDweb Interface
A tool for visualizing , analyzing, and retrieving MAS simulation results
Please choose either a Carrington Rotation or a date of interest and then select from the options:
• Overview, which presents a photogallery of images summarizing the simulation;
• Plot Data, which provides a set of interactive tools to plot, visualize, and analyze the data;
• Retrieve Data, which allows you to download the data for offline analysis
Carrington Rotation
(1625 - 2007)
Coronal Solution
Heliospheric Solution
Date (mm/dd/yyyy)
(03/18/1975 - 09/25/2003)
HOME
OVERVIEW
PLOT DATA
RETRIEVE DATA
Send comments/suggestions to: webmaster@iMHD.net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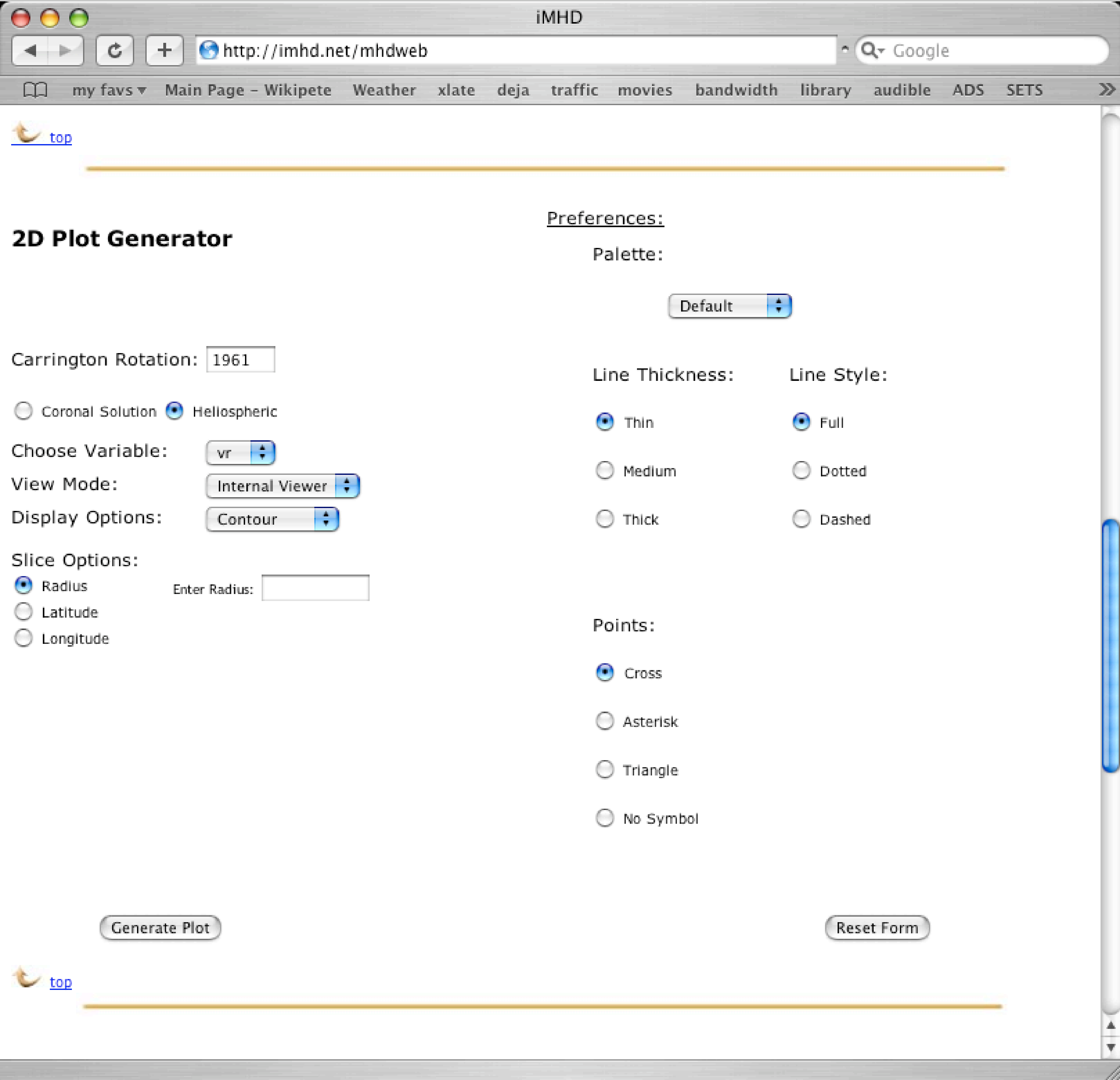
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Carrington Rotation: 1961
Coronal Solution
Heliospheric
Choose Variable: vr
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Display Options: Contour
Slice Options:
Radius
Latitude
Longitude
Enter Radius:
Line Thickness:
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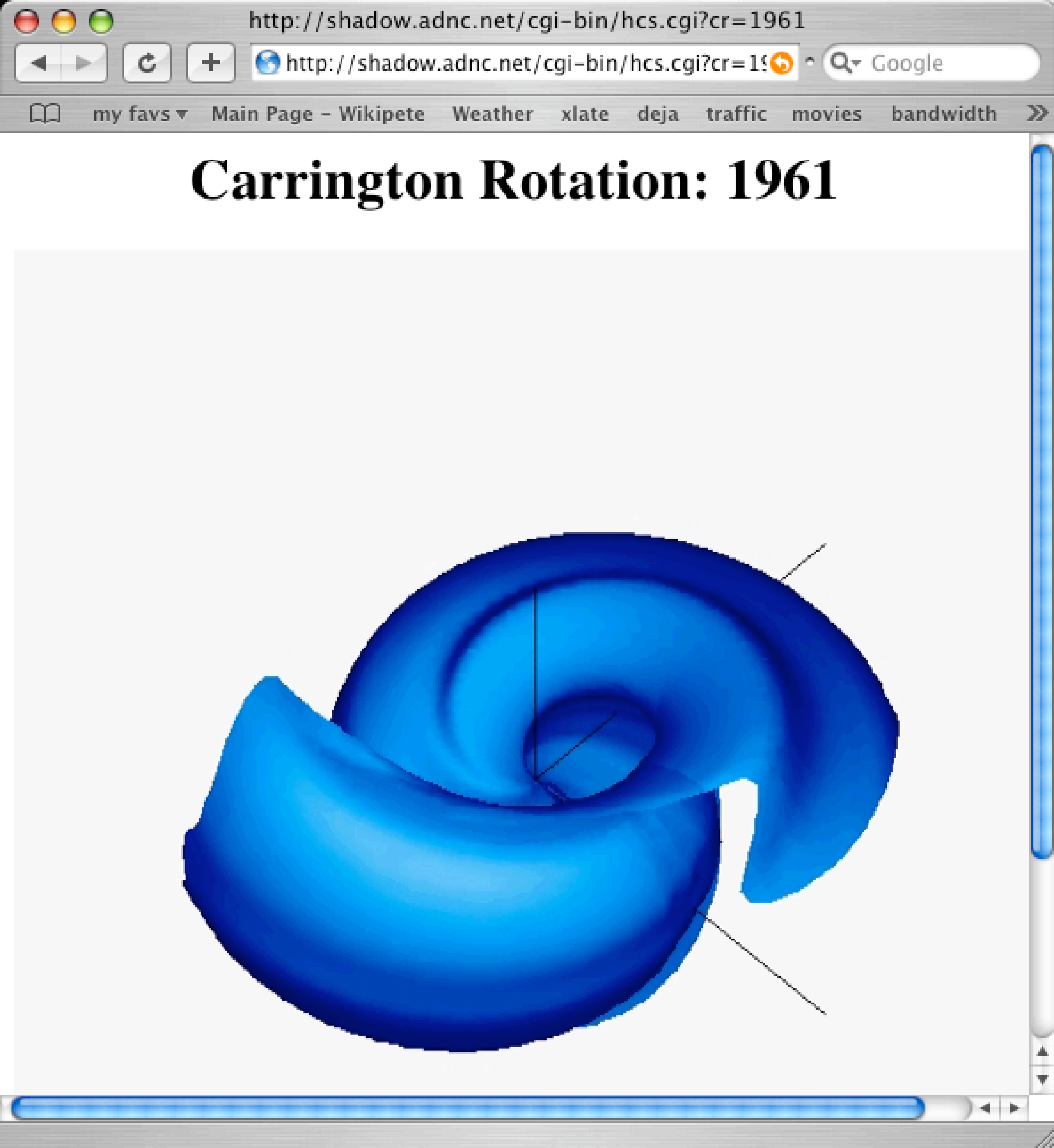
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bandwidth
Carrington Rotation: 1961

iMHD MHDweb Interface

A tool for visualizing , analyzing, and retrieving MAS simulation results

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iMHD Data Retriever

The simulation results for Carrington rotation 1961 are listed below, with a brief explanation next to it. Each file contains one magnetofluid parameter. Click on the link to download the file.

The data files are in HDF format. At the bottom of the page, there are two routines to help you read the data; one written in IDL and the other written in Fortran 90.

Finally, the time histories of some of the parameters are also given in addition to the output log file for the run.

Radial Component of the Magnetic Field, Br	Radial Component of Velocity, Vr	Time Histories - Part 1
Theta Component of the Magnetic Field, Bt	Phi Component of Velocity, Vp	Time Histories - Part 2
Phi Component of the Magnetic Field, Bp	Theta Component of Velocity, Vt	Output Log File
Thermal Pressure, P	Density, Rho	

Carrington Rotation: 1961

Heliospheric Solution

HOME OVERVIEW PLOT DATA RETRIEVE DATA

Send comments/suggestions to: webmaster.net
